ABBP.

ISSN 0840-8440

PROCEEDINGS

TECHNOLOGY TRANSFER CONFERENCE 1988

November 28 and 29, 1988

Royal York Hotel

Toronto, Ontario

SESSION C

LIQUID AND SOLID WASTE

Sponsored by

Research and Technology Branch

Environment Ontario

Ontario, Canada

CP8

Enhanced Biodegradation of Aromatic and Chlorinated Aliphatic Compounds in a Leachate-Impacted Aquifer

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A three year research study was undertaken in April 1987 to evaluate the persistence of selected organic compounds in the shallow, anaerobic leachate plume occurring in sands adjacent to a municipal landfill site in North Bay, Ontario. Research to date has focused on developing and evaluating methods for the enhanced *in situ* bioremediation of selected aromatic hydrocarbons (benzene, toluene, ethylbenzene, xylenes, chlorobenzene, trimethylbenzene and naphthalene) and chlorinated aliphatic compounds (carbon tetrachloride, trichloroethane, and tetrachloroethylene). In previous studies of organics in landfill leachate plumes, these compounds were among the most common contaminants.

The approach of this study has been to investigate the natural persistence of the target compounds by evaluating their distribution in the landfill leachate plume, and by conducting controlled experiments simulating the actual field conditions as closely as possible. To date, laboratory microcosm experiments, *in situ* biodegradation columns, and natural gradient injection experiments have been attempted, and represent increasing degrees of realism and complexity.

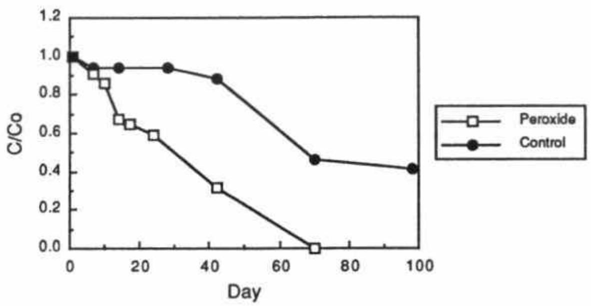
Laboratory Microcosm Experiments

These experiments investigated the enhanced biodegradation of aromatic and chlorinated aliphatic compounds in aquifer material from the North Bay landfill site. Active microcosms were amended with remediating solutions of alternate electron acceptors (peroxide and nitrate) and primary substrates (glucose and acetate) to enhance natural biodegradation processes. Attenuation of organic compounds in remediated microcosms was compared to unremediated and sterile controls to assess the effectiveness of the remedial method.

Minor losses of the target compounds in sterile microcosms was attributed to sorption and diffusion. Additional mass losses in control microcosms were attributed to natural biodegradation processes. Rapid attenuation of carbon tetrachloride and accumulation of chloroform in unremediated microcosms was attributed to reductive dechlorination by anaerobic bacteria. The presence of nitrate

appeared to inhibit this process. Denitrification of non-specific organic carbon was observed in nitrate-remediated microcosms, but none of the target aromatic hydrocarbons attenuated significantly. Glucose substrate addition was successful in increasing the denitrifying biomass. Significantly greater degrees of attenuation were observed in peroxide remediated microcosms, compared to unamended and nitrate-remediated microcosms (figure 1). Acetate-remediated microcosms showed no significant mass losses of the target compounds. The presence of denitrifying, sulphate-reducing, and methanogenic cultures in the microcosms was confirmed by additional tests.

Figure 1: Effect of Peroxide Addition on Toluene Biodegradation



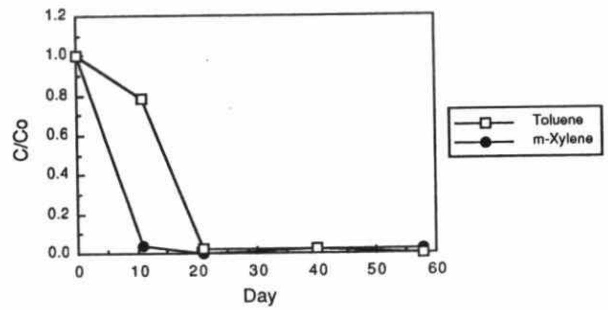
The results indicate that enhanced biodegradation of the target compounds is possible in the North Bay aquifer. Natural, unamended biodegradation of some compounds does occur in the North Bay aquifer, at much slower rates.

In situ Biodegradation Column Experiments

In situ biodegradation columns permit the investigation of enhanced biodegradation of organic compounds in a realistic field situation, while still maintaining the precise control of a laboratory experiment. The columns were pounded into the aquifer below the water table, and approximately four pore volumes of leachate was pumped out of the columns, spiked with a conservative tracer, organic compounds and remediating solutions, and then pumped back into the column. Periodic sampling of the pore water in the column allowed precise monitoring of the biodegradation processes at work in the aquifer.

Nine separate *in situ* biodegradation columns were installed at the North Bay site, which investigated both unremediated and remediated rates of biodegradation of twelve target compounds. Experiments conducted to date have investigated denitrifying, sulphate-reducing and methanogenic bacteria. The sulphate-reducing bacteria were capable of significant biotransformations of toluene and m-xylene compared to unremediated rates observed in microcosm experiments. Typical results are shown in figure 2. All of the target compounds, except carbon tetrachloride, were persistent in the nitrate-remediated columns. These results complement the findings from the laboratory microcosm experiments and represent a more realistic view of the biodegradation processes active in the North Bay aquifer.

Figure 2: Toluene and m-Xylene Biodegradation in Sulphate-Remediated Columns



Natural Gradient Injection Experiments

Natural gradient injection experiments represent the most realistic simulation of the fate of organic compounds under natural conditions. This is accomplished by introducing a large slug of water into the aquifer, spiked with a conservative tracer and organics of interest, and allowing the slug to migrate at the groundwater velocity.

Field work was undertaken at the North Bay site during the summer and fall of 1987 with the objective of performing a large scale conservative tracer injection test to establish the hydraulic aspects of the experimental site prior to conducting *in situ* biodegradation experiments. An initial sampling grid of 63 multilevel piezometers

was installed at a grid spacing of 1 m and covered an area of approximately 8 m by 8 m. This network was subsequently expanded by the installation of two fences of multilevel piezometers 24 m and 36 m from the injection site.

Approximately 4800 L of city water containing 200 mg/L sodium bromide was injected over a 12 hour period in August 1987. Conductivity measurements the following day failed to indicate the presence of the plume. Samples collected from the piezometer network were analyzed for bromide, chloride and background aromatic hydrocarbon concentrations. None of the samples showed any evidence of the bromide-spiked plume.

Given the puzzling results of the large-scale injection, we concluded that the flow system in the vicinity of the injection was not as foreseen based on previous work at the site. To improve our understanding of the very local flow system, we conducted a freshwater injection experiment supplemented by an extensive aquifer coring and water table mapping program.

Coring in the area of the piezometer network revealed that the aquifer was much more heterogeneous than previously expected, with individual layers ranging from coarse sand to fine silt. Continuous monitoring during a nine hour injection of 3600 L of fresh water showed development of a 3 m by 3 m plume which migrated at approximately 1 m/day. Once developed, this plume showed evidence of vertically separating into distinct layers, due to hydraulic conductivity contrasts in the aquifer.

The extremely heterogeneous nature of the North Bay aquifer, and the fast groundwater velocities preclude the possibility of monitoring the mass balance of a large-scale injection experiment. Our efforts will now concentrate on introducing a continuous plume over an extended period, while monitoring the plume at several locations downgradient. This approach will focus on the biodegradation capabilities of the indigenous bacteria rather than the potentially complicated aspects of groundwater transport.

In summary, the research undertaken at the North Bay landfill site combines laboratory and field experiments of increasing complexity and realism to study the potential for enhanced *in situ* biodegradation of aromatic and chlorinated aliphatic compounds. The results to date demonstrate that this technique is a potentially viable alternative for remediating anaerobic, leachate-impacted aquifers.